Naval Research Laboratory
Washington, DC 20375-5320

NRL/MR/5621--99-8364

Dark HORSE 2 Quick-Look Report: Real-time Detection of Military Ground Targets Using an Infrared Hyperspectral Imaging Sensor

CHRISTOPHER M. STELLMAN
FRANK BUCHOLTZ
JOSEPH V. MICHALOWICZ

Advanced Concepts Branch
Optical Sciences Division

April 15, 1999

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	April 15, 1999	Memorandum report

4. TITLE AND SUBTITLE

Dark HORSE 2 Quick-Look Report: Real-time Detection of Military Ground Targets Using an Infrared Hyperspectral Imaging Sensor

5. FUNDING NUMBERS

6. AUTHOR(S)

Christopher M. Stellman, Frank Bucholtz, and Joseph V. Michalowicz

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/5621--99-8364

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5660

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

A

13. ABSTRACT (*Maximum 200 words*)

Researchers at the Naval Research Laboratory (NRL) have successfully demonstrated autonomous, real time detection of military ground targets using a long-wave infrared hyperspectral imaging sensor. The work was performed under NRL's Dark HORSE effort, the culmination of a four-year Multispectral Overhead IR/EO Surveillance (MOVIES) program to develop real-time hyperspectral detection, cueing, target location, and target designation capabilities. The following provides an overview of Dark HORSE 2 (DH2), the recently completed second phase of the Dark HORSE effort. The DH2 hyperspectral sensor system is described in detail along with a recent field experiment in which it was employed. The system hardware components, software interface and processing methods are described in detail. In closing, a description of the test flight profiles is given and a preliminary analysis of the collected data is presented.

14. SUBJECT TERMS

Hyperspectral Detection
Remote Sensing

15. NUMBER OF PAGES

29

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

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DARK HORSE 2 - REAL-TIME DETECTION OF MILITARY GROUND TARGETS USING AN INFRARED HYPERSPECTRAL IMAGING SENSOR

1. EXECUTIVE SUMMARY

The Dark HORSE 2 program has realized the following accomplishments:

- Successfully integrated real-time processor with SEBASS LWIR system.
- Demonstrated real-time airborne LWIR detection of targets with good ROC performance using two simultaneous anomaly detection algorithms (s-RX and LBG).
- Fully corrected, calibrated LWIR data cubes obtained in real-time.
- Obtained high-quality data sets (LW&MW) for use in development of tactically-robust algorithms.

2. INTRODUCTION

The need for strategic military surveillance of critical ground targets has been well recognized in the military community. Multispectral and hyperspectral sensors offer the possibility of exploiting the spectral differences between targets of interest and local backgrounds as a detection discriminant. In addition, rapid developments in computing power and anomaly detection algorithms have led to the possibility of real-time target identification and location. These developments combined with the results of NRL's four-year Multispectral Overhead IR/EO Surveillance (MOVIES) program [1] have led to Project Dark HORSE, a four-year four-phase follow on program to develop real-time hyperspectral detection, cueing and target location capabilities. In the first phase of this program, Dark HORSE 1, it was demonstrated that a visible hyperspectral sensor could be used for the autonomous, real-time detection of airborne and military ground targets [2-4]. In the recently completed second phase of the program, Dark HORSE 2, it has been demonstrated that a long-wave infrared hyperspectral sensor can be used in the same manner, with the advantages of improved detection performance and day/night flying capabilities.

The following provides an overview of the Dark HORSE 2 (DH2) long-wave infrared (LWIR) hyperspectral sensor system and the recent field experiment in which it was employed. The system hardware components, software interface and processing methods are described in detail. A description of the test flight profiles is given and a preliminary analysis of the collected data is presented.

Manuscript approved March 10, 1999.

3. DATA COLLECTION INSTRUMENT (Dark HORSE 2)

The complete DH2 system is composed of three components, a mid wave infrared (MWIR) and long wave infrared (LWIR) hyperspectral sensor, a sensor controller and a real-time processor. Respectively, Figure 1, Figure 2 and Figure 3 show the sensor, the controller, and the real-time processor installed aboard a Twin Otter aircraft (Figure 4), the airborne platform used for this field test. The hyperspectral sensor and sensor controller, SEBASS (Spatially Enhanced Broad-band Array Spectrograph System), were provided by the Aerospace Corporation, Los Angeles, CA. The Space Computer Corporation, Santa Monica, CA Monica and the Naval Research Laboratory, Washington, DC, jointly developed the real-time processing system.

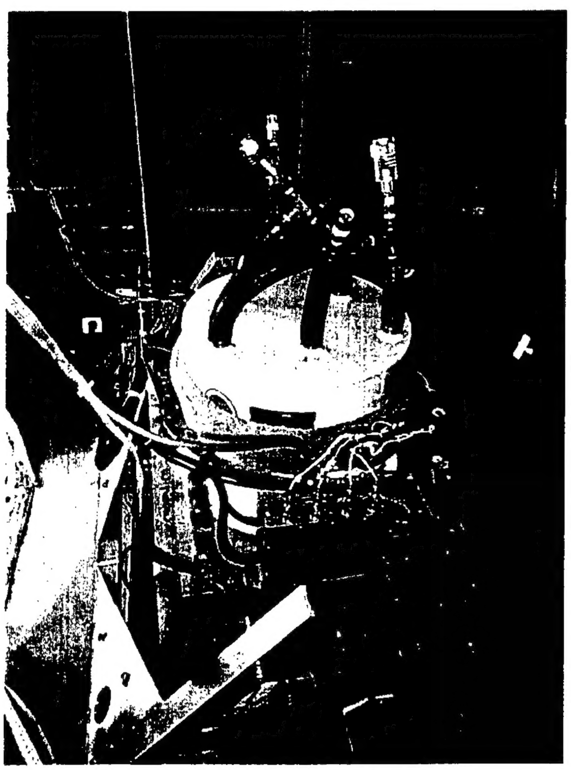

Figure 1: Dark HORSE 2 Sensor (SEBASS).

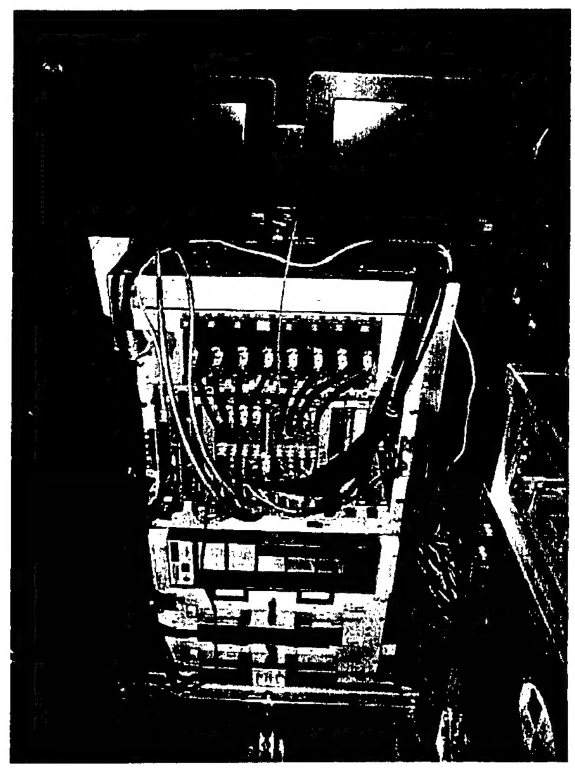

Figure 2: Dark HORSE 2 System Controller.

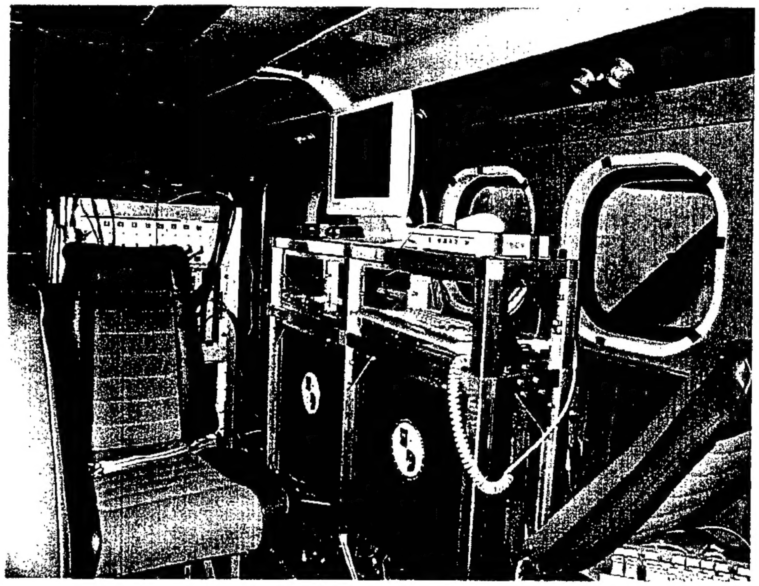

Figure 3: Dark HORSE 2 Real-Time Processing System.

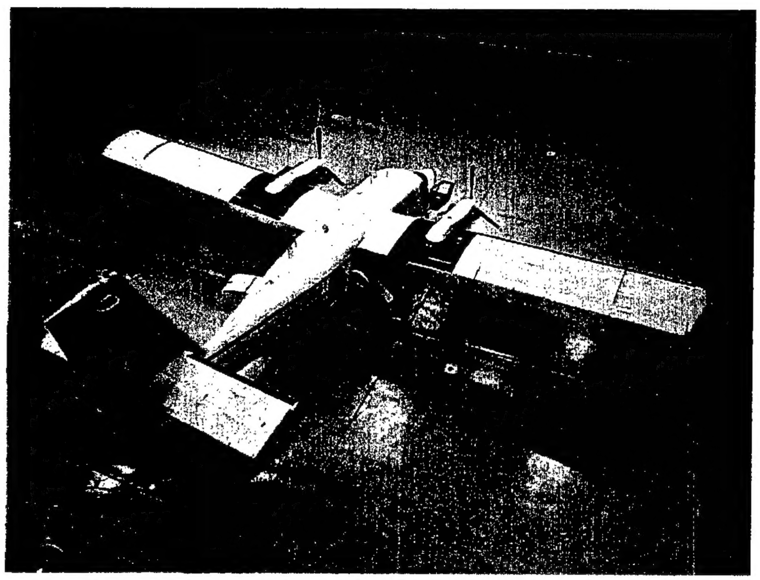

Figure 4: Dark HORSE 2 Airborne Platform – Twin Otter.

The hyperspectral sensor is a dispersive imaging spectrograph operating concurrently in the MWIR and LWIR spectral regions with broad-band spectral coverages of (2.5 - 5.3 μm) and (7.8 – 13.4 μm), respectively. The system is ruggedized for airborne applications and has demonstrated high stability and low noise performance. The sensor operates in a pushbroom mode by forming a dispersed image of the entrance slit onto the two two-dimensional arrays. The two focal plane arrays, one for the MWIR and one for the LWIR, are each 128 x 128 pixels x 14 bits deep. For both arrays one dimension gives spectral

information and the other dimension gives spatial information in the cross-track direction cross-track. Scanning the slit across the scene of interest using aircraft motion gives spatial information in the down-track direction and results in a three-dimensional hyperspectral data cube. The sensor operates in a nadir-only mode with an instantaneous field of view per pixel of approximately 1 mrad. Nadir-only viewing is accomplished using a roll stabilization platform. Pitch and yaw stabilization and forward velocity correction are not employed.

Figure 5 shows the optical layout of the spectrograph. Light from the scene of interest is imaged on the spectrograph entrance slit by a three-mirror anastigmatic telescope whose f/ratio is f/7.2. A dichroic beamsplitter that reflects wavelengths shorter than 6.5 μm and transmits longer wavelengths separates light exiting the slit. Use of the dichroic beamsplitter guarantees that both spectrograph channels view the same scene simultaneously. Long wavelength light is dispersed by a spherical-faced prism/conic mirror combination and is imaged onto a focal plane array through a zinc selenide lens. The mid-wave infrared light, which is reflected by the dichroic beamsplitter, is dispersed by a spectrograph that is similar in design to the LWIR channel but uses a lithium fluoride prism. The LWIR and MWIR channels each have a resolution of about 4 cm^{-1} or 0.050 μm per pixel and 0.025 μm per pixel, respectively.

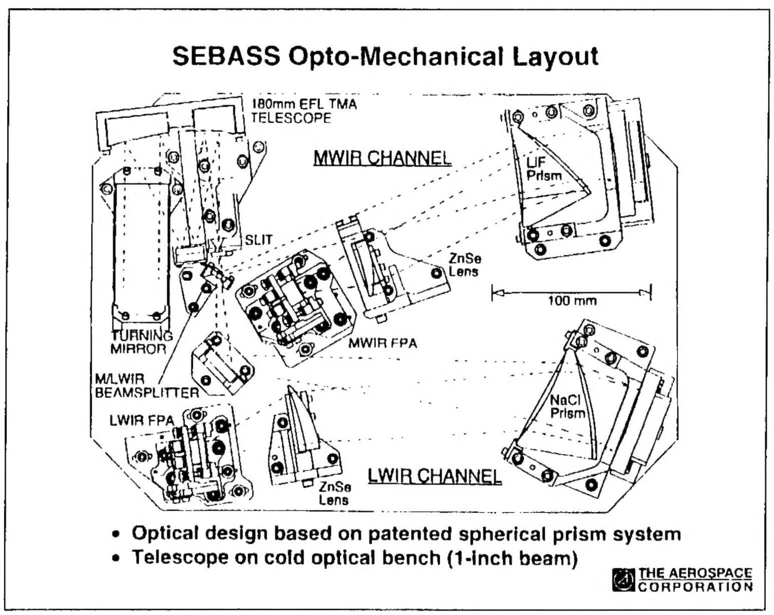

Figure 5: Dark HORSE 2 (SEBASS Sensor) Opto-Mechanical Layout.

The sensor is controlled by a Sun Sparc-20 computer using a data handling system built around a VME bus system. The user interface provides a method of entering required input parameters such as archival file names and camera frame rates and provides a means of starting and stopping data collections.

The controller is also responsible for all data handling. Figure 6 is a schematic of the sensor controller's data handling system. All of the clock signals that control the operation of the focal plane multiplexers and the timing signals for the analog-to-digital converters are generated by a programmable microsequencer whose timing control can be adjusted in 67 nanosecond increments. Each array has four independent channels that read the signals from four consecutive pixels along the spectral axis per clock cycle. The four analog signals from the arrays are amplified and converted to digital data by high-speed 14-bit analog-to-digital converters. The digital data are passed directly to a special-purpose "co-adder" board that computes the difference between the signal and reset values and co-adds data from successive frames. Although the system is capable of taking data without differencing, it typically operates in a mode where the signal is computed as the difference between the voltage at the end of integration and the voltage when the multiplexer is reset. This approach reduces common-mode noise at the cost of a small increase in random noise since two noisy voltage readings are differenced. Differencing also avoids problems with dc drifts in the preamplifiers that can introduce systematic errors in the measured signal.

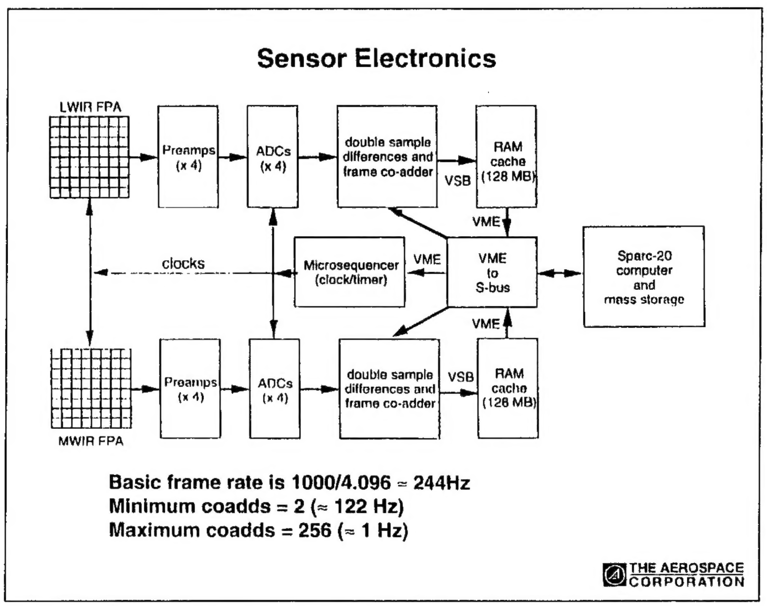

Figure 6: *Dark HORSE 2 (SEBASS Sensor) Schematic Diagram of the Data Handling System.*

Each frame of data can be digitally co-added to the sum of a selectable number of previous frames using a 24-bit adder. This feature allows frame data to be stored at a slower rate than the focal plane frame rate. At the read rate of four pixels per clock cycle and a cycle interval of 1 μsec, the entire array is read in 4096 μsecs, which is approximately a rate of 244 frames per second. At a lower frame rate the multiplexer summing capacitor would become saturated before the end of the integration time. The co-adder effectively

allows the infrared signal to be integrated off the multiplexer without loss of signal; it also allows the output frame rate to match the rate at which the image moves across the ground. For example, the Twin Otter aircraft used for this experiment had a typical ground speed of 120 knots or about 62 meters per second. Thus, to achieve one sample in a ground distance of 1 meter, four successive data frames were added together to give an effective output data rate of 61 frames per second. During a collection data from the co-adder is sent to a cache RAM that has a 384 Mbyte (6134 frame) capacity. At the end of each data collection, data from the cache RAM is transmitted via a VME bus to the host Sparc-20 computer for storage to disk and tape.

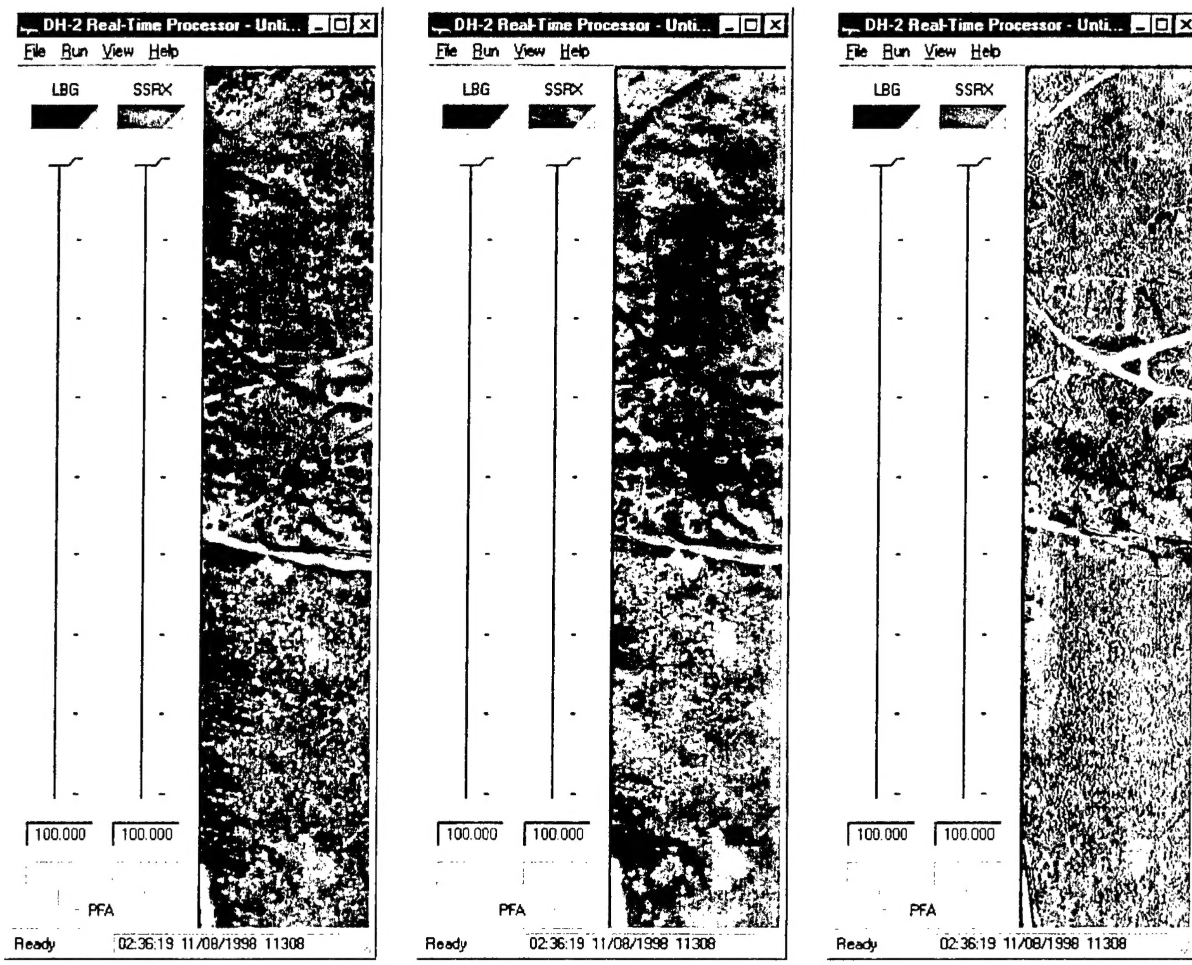

Figure 7: Available Dark HORSE 2 Waterfall Displays.

Broadband (left), 3-Color Spectral Composite (middle) and 3-Band Principal Component Composite (right).

Two anomaly detection algorithms, a subspace RX [3,5,6] and LBG clustering [3,7-9] algorithm, are run in parallel using a real-time data processing system. The real-time processing system consists of two

200 MHz Pentium Processors with DSP subsystems (8 Analog Devices SHARC). The first processor performs flat fielding, bad pixel interpolation, smile correction, spectral binning, radiometric calibration, and archives all raw and calibrated data. The second processor runs the two detection algorithms, generates cue files, outputs waterfall display data, and archives all detector outputs, target cues and user inputs. A custom software application runs under the Microsoft Windows NT operating system and provides the user a means of changing algorithm parameters and thresholds. The software also gives the user data output in the form of a several different real-time waterfall displays, based on a broadband spectral output, a 3-color spectral composite output or a 3-band principal component composite output (Figure 7).

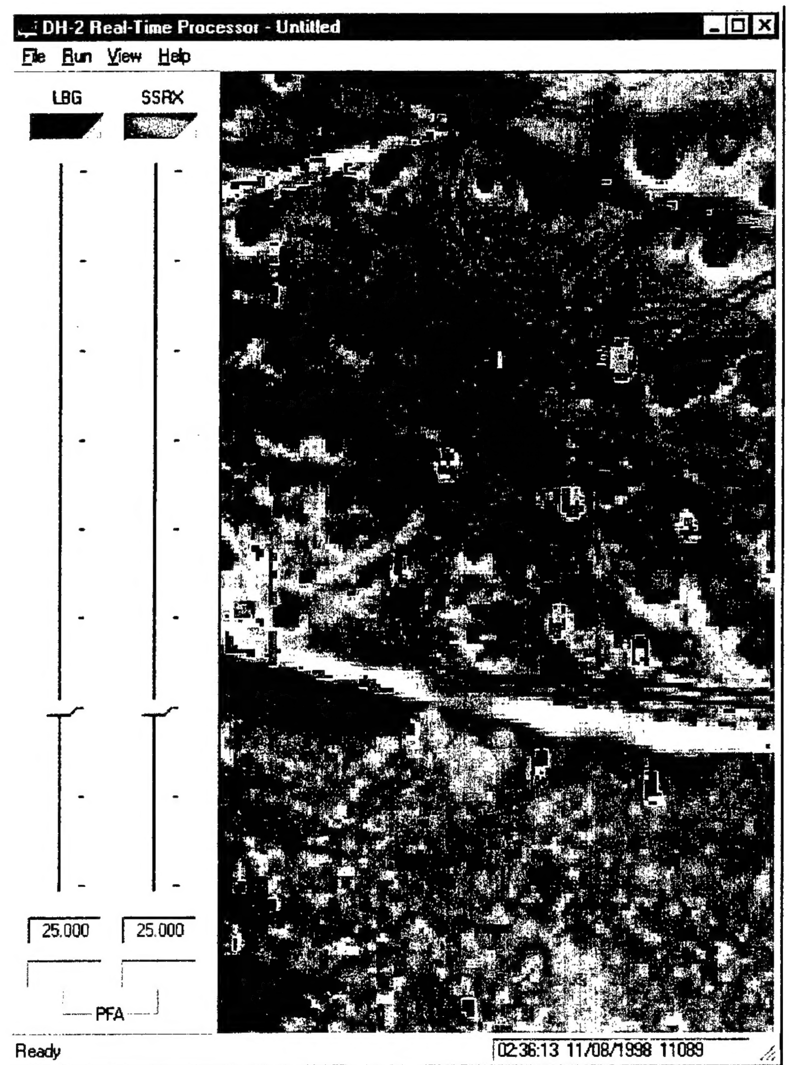

Figure 8: Dark HORSE 2 Waterfall Display Showing Anomalous (Cued) Pixels.
RX detection (red), LBG detection (blue) and coincident detection (green).

During operation, the waterfall display can be overlaid with a map of the anomalous (cued) pixels. Figure 8 shows a portion of a Dark HORSE waterfall display over a region of interest. The display highlights pixels identified as anomalous by RX detection (red), LBG detection (blue) and coincident detection (green). It should be noted that all of the targets of interest used in this field test could be identified with acceptably low false alarm rates using coincident detection. Algorithm performance is discussed below in greater detail.

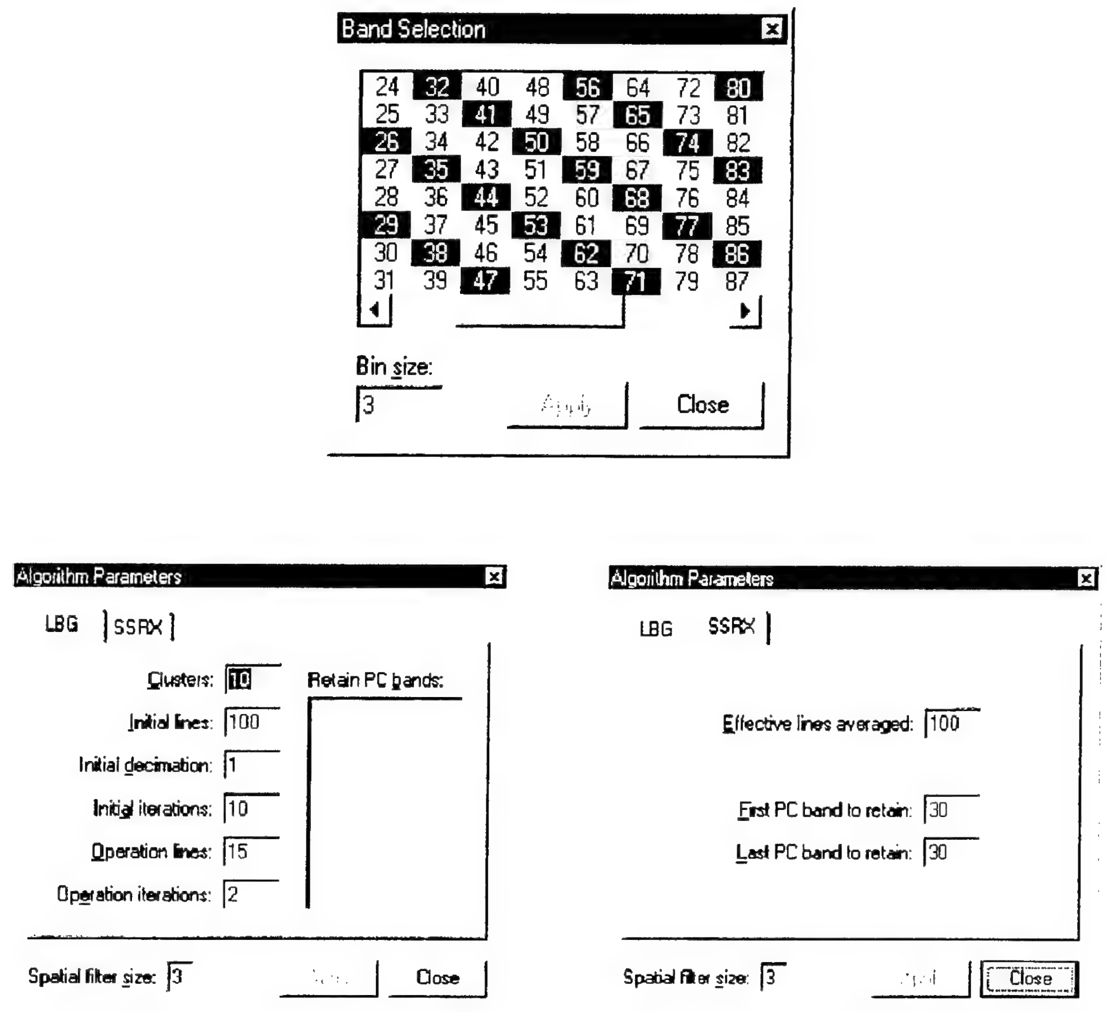

Figure 9: Dark HORSE 2 Real-Time Processing System Prameters Listing User Interfaces

For the subspace RX algorithm the user can define the wavelength bands used for spectral analysis, the number of lines used for recursive filtering, the PC bands used for RX data modeling and size of the employed spatial filter (Figure 9). For the LBG clustering algorithm the user can define the wavelength bands used for spectral analysis, the number of clusters employed, the number of lines used for initialization and decimation, the number of clustering iterations used during initialization and operation, and the size of the employed spatial filter (Figure 9).

The following provides an overview of system specifications for the hyperspectral sensor and controller and real-time processor. Some typical flight parameters are also listed.

Hyperspectral Sensor and Controller (Developed by Aerospace)	
Spectrometer Type	Dispersive Prism
MWIR Wavelength Range	2.5 - 5.3 μm
LWIR Wavelength Range	7.8 – 13.4 μm
MWIR CCD Array	128 x 128 PtSi
LWIR CCD Array	128 x 128 PtSi
Frame Rate	244 Hz with 4 co-adds = 61 Hz
Pixel Depth	14 bit
Output Data Size (Raw)	128 Pixels x 128 Bands x 16 bit Precision

Real-Time Processor (Developed by SCC and NRL)	
Platform	Pentium Pro, 200 MHz
DSP Processor	8 Analog Devices SHARC
Peak Processor Power	> 1Glop/s
Algorithm #1	Subspace RX with Spatial Filtering
Algorithm #2	LBG Clustering with Spatial Filtering
Output Data Size (Calibrated)	128 Pixels x 30 Bands x 32 bit Precision

4. FIELD DATA

All field data were collected over the Chicken Little Compound, Eglin Air Force Base, FL during the dates of November 1-10, 1998. An aerial photo of the compound is shown in Figure 10. Outlined on this photo are six of twelve target sites. The target sites (#3, #4, #5, #6, #7, #9) were of interest for this collect due to the military vehicles and/or materials that were present. Vehicles of interest included T-72 tanks, 2S-3 152mm self-propelled howitzers, 2S-1 122mm self-propelled howitzers, ZIL-131 trucks, GAZ-66 trucks, artillery command and reconnaissance vehicles (ACRVs), artillery radars (Big Freds), MAZ-543 P Transporter-Erector-Launchers (TELs), SS-1 Scud B missiles, ZIL-131 support vehicles, BTR-70 APC security vehicles, SA-06 SAM TELs, SA-08 SAM TELs, SA-13 SAM TELs, URAL-4320 reload vehicles, URAL-375 surrogate radar vehicles and ZSU-23-4 quad 23mm self-propelled anti-aircraft gun systems. Materials of interest included various aluminum panels (CARC, black-sprayed and flame-sprayed), aluminized plastic panels, fiber-glass panels, rubber sheets, military canvases and parachutes, Swedish Barracuda camo kits, TRACOR CC&D camo kits, Soviet Woodland camo kits, East German Garnish and Woven camo kit, and a diverse range of soil types and moisture contents, ranging from untrafficable (pond, marsh) to trafficable.

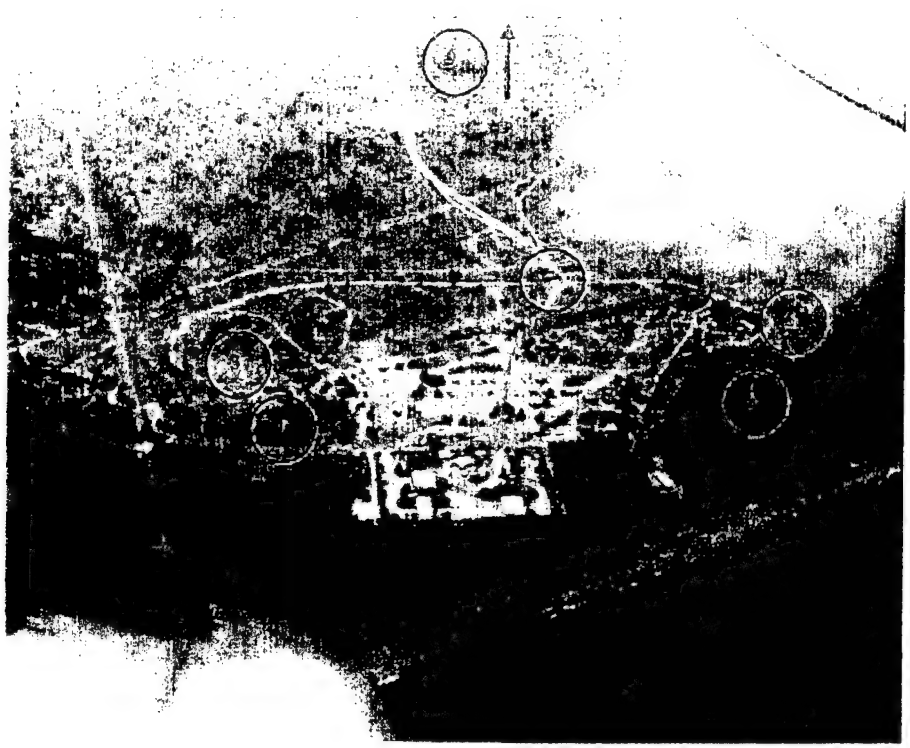

Figure 10: Aerial Photo of the Chicken Little Compound, Eglin Air Force Base, FL.

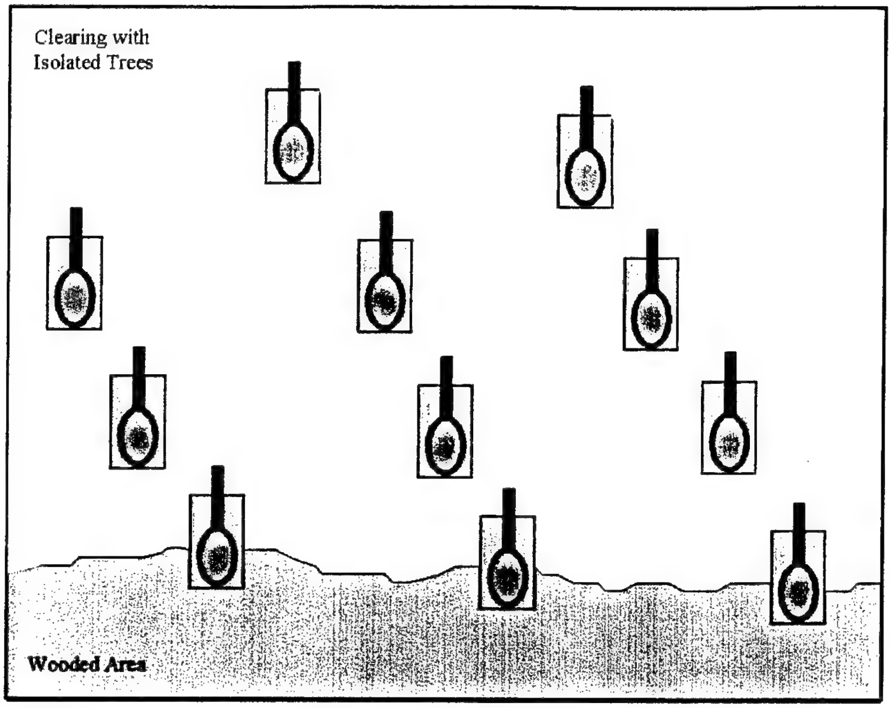

Figure 11: Site 4 Relative Target Locations.

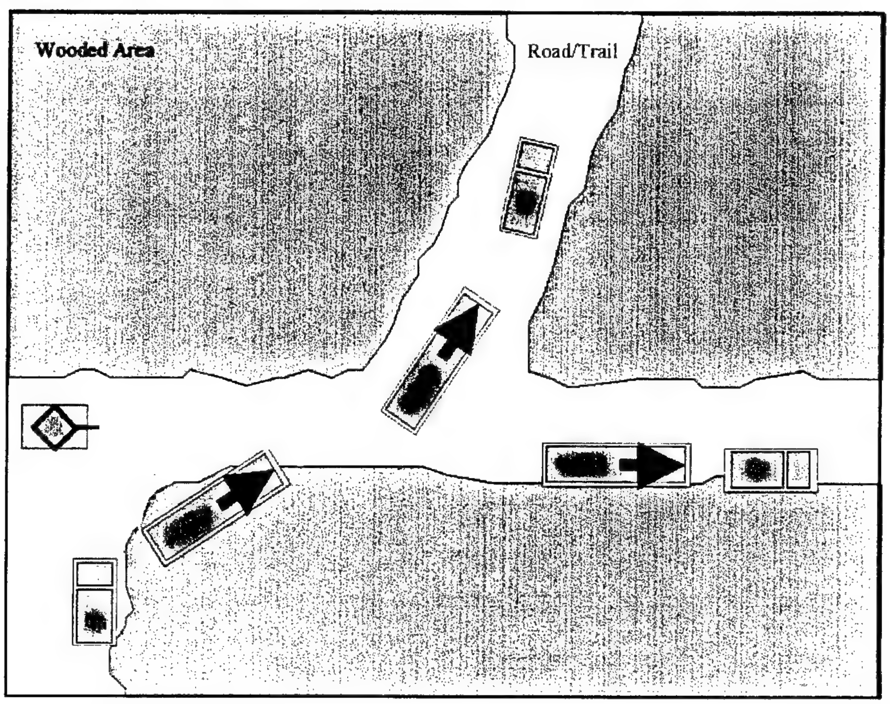

Figure 12: Site 6 Relative Target Locations.

Preliminary analysis of the collected data has been performed on the LWIR data, which is known to be of better quality than the MWIR data. Also, for the purposes of these preliminary studies only data sets pertaining to mission 3 site 4 and mission 3 site 6 have been examined for algorithm performance. These sites have been chosen because the targets are known to be of strong interest to the military community. Furthermore, site 4 has been emphasized because the performance of the currently used RX and LBG algorithms will be compared to future change detection algorithms (that are currently under development). Figure 11 and Figure 12 outline the relative positions of the targets for site 4 and site 6 respectively.

All field data were collected at altitudes between 850 and 870 m and at relative ground speeds between 110 and 120 m/s. For this study the sensor collected data using both the MWIR and LWIR detectors operating at a co-added frame rate of 61 Hz. This resulted in a hyperspectral cross-track ground pixel size of 0.9 m and a down-track ground pixel size of 1.0 m. The number of frames collected for each of the data collects ranged between 500 and 4500 frames and corresponding path lengths of 500 and 4500 meters, respectively. Measurements were collected under varying combinations of cloud cover (clear to cloudy) and light conditions (mid-day to mid-night). In total 83 field data sets were collected and 65 of those data sets have been deemed "good" based on a preliminary quick-look analysis. A detailed listing of the collected data sets with file names and brief annotations is provided in the appendix.

5. RESULTS AND DISCUSSION

Figure 13 and Figure 16 show a series of images used in determining the performance of the RX and LBG algorithms for site 4 and site 6. For both figures the first image (A) is a broadband image of the collected data used for identification of the target region of interest. The second image (B) is a 3-color principal component (PC) image used for making a target truth mask. The truth mask has been overlaid and the targets are highlighted in pink. The third image (C) is the RX detection output using optimized algorithm parameters. The detected pixels are highlighted in red. And finally, the fourth image (D) is the LBG detection output using optimized algorithm parameters with the detected pixels highlighted in blue. It should be noted that the presented images only represent a subset of the collected data sets. The data sets were examined in their entirety when determining algorithm performance.

Respectively, Figure 14 and Figure 15 show the RX and LBG Receiver Operating Characteristic (ROC) curves for site 4. Figure 14 gives an overlay of RX ROC performance using the in-flight algorithm parameters (dashed black line) and using the post-flight optimized algorithm parameters (solid red line). For the in-flight RX analysis the thermal PC (PC1) and the leading five color PCs were projected out. For the post-flight RX analysis the thermal PC and only the first two color PCs were projected out. Figure 15 gives an overlay of LBG ROC performance using in-flight (dashed black line) and post-flight algorithm

parameters (solid blue line). The in-flight LBG analysis employed eight background-dominated color PCs and clustered data into ten classes while the post-flight LBG analysis retained all 29 color PCs and used only three classes. As expected, Figure 14 and Figure 15 show that the algorithms perform better using the optimized post-flight parameters. It is also evident from Figure 14 and Figure 15 that for a 50% Probability Of Detection (P_D) a False Alarm Rate (FAR) on the order of one to ten per square kilometer is achievable.

Figure 16 and Figure 17 show the RX and LBG ROC curves for site 6. Like the previous figures an overlay of RX and LBG ROC performance using in-flight and post-flight optimized algorithm parameters are shown. Some algorithm parameters are different from those used for site 4. For the in-flight RX analysis the thermal PC (PC1) and the leading eleven color PCs were projected out and for the post-flight RX analysis, the thermal PC and the first two color PCs were projected out. The in-flight LBG analysis employed eight background-dominated color PCs and clustered data into ten classes and the post-flight LBG analysis retained all 29 color PCs and used only five classes. Again, as expected, the algorithms perform better using the optimized post-flight parameters. However, at a 50% P_D site 6 gives a somewhat higher FAR ($\geq$ ten per square kilometer) than that achieved for site 4.

It should be noted that for both site 4 and site 6 the RX algorithm performs significantly better than the LBG algorithm. An evaluation of algorithm fusion and its effects on performance is currently under way. Based on the results of Dark HORSE 1 it is expected that some improvement in reducing FAR for a given P_D will be achieved. The evaluations of several other algorithms are also currently under investigation. While a detailed explanation of these algorithms is far beyond the scope of this document a brief list follows. Algorithms employing traditional matched filter methods and matched filter variants, such as interrupted matched filters and subspace interrupted matched filters are being explored. Algorithms based on background modeling are also under development. These include linear mixing model, stochastic mixing model and clustering based methods. In addition to these purely spectral based algorithms there are also ways to exploit other degrees of freedom available in the collected data sets. Chronochrome target detection (change detection) is being examined as a means of identifying targets through exploitation of spectral changes over time. Finally, the use of spatial information is also being pursued. Efforts to use texture models to identify targets and spectral based region growth methods to cluster spatially related pixels are both under way. The fusion of the above detection algorithms is expected to greatly reduce FARs and the results of these studies will be presented in future documents.

Figure 13: Mission 3 Site 4 Detection Results. (A) Broadband Image, (B) Color PC Image with Target Truth Mask, (C) Optimized RX Detection Output and (D) Optimized LBG Detection Output.

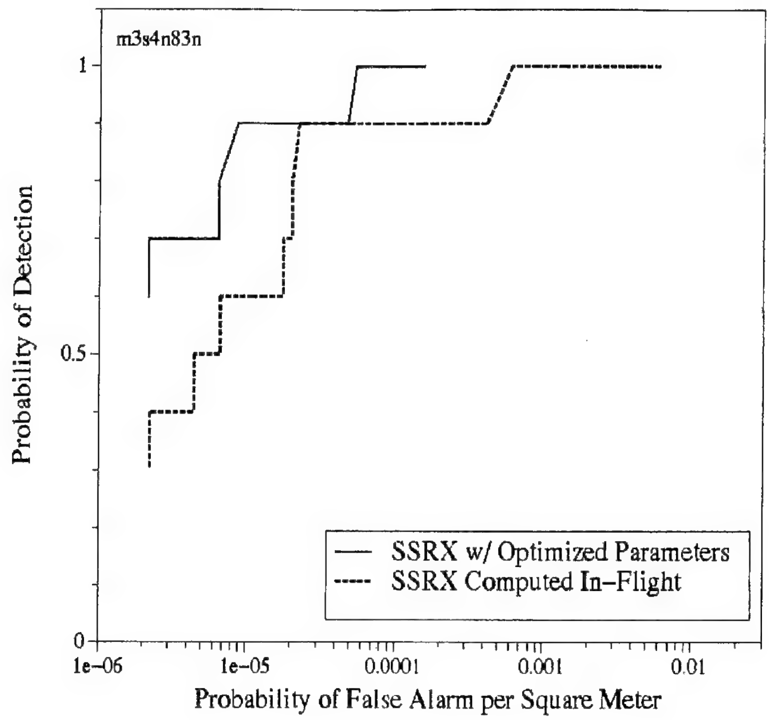

Figure 14: Mission 3 Site 4 RX Detection Results.

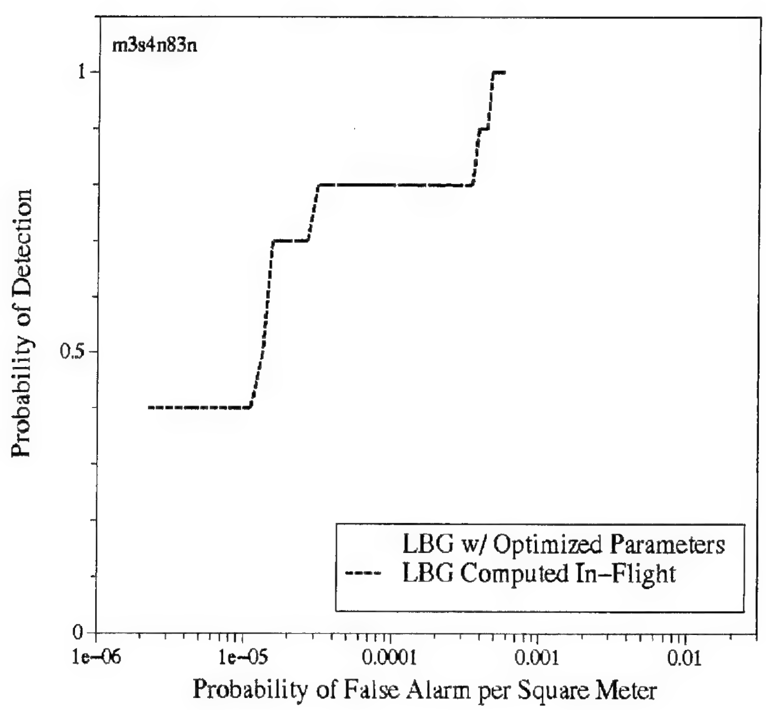

Figure 15: Mission 3 Site 4 LBG Detection Results

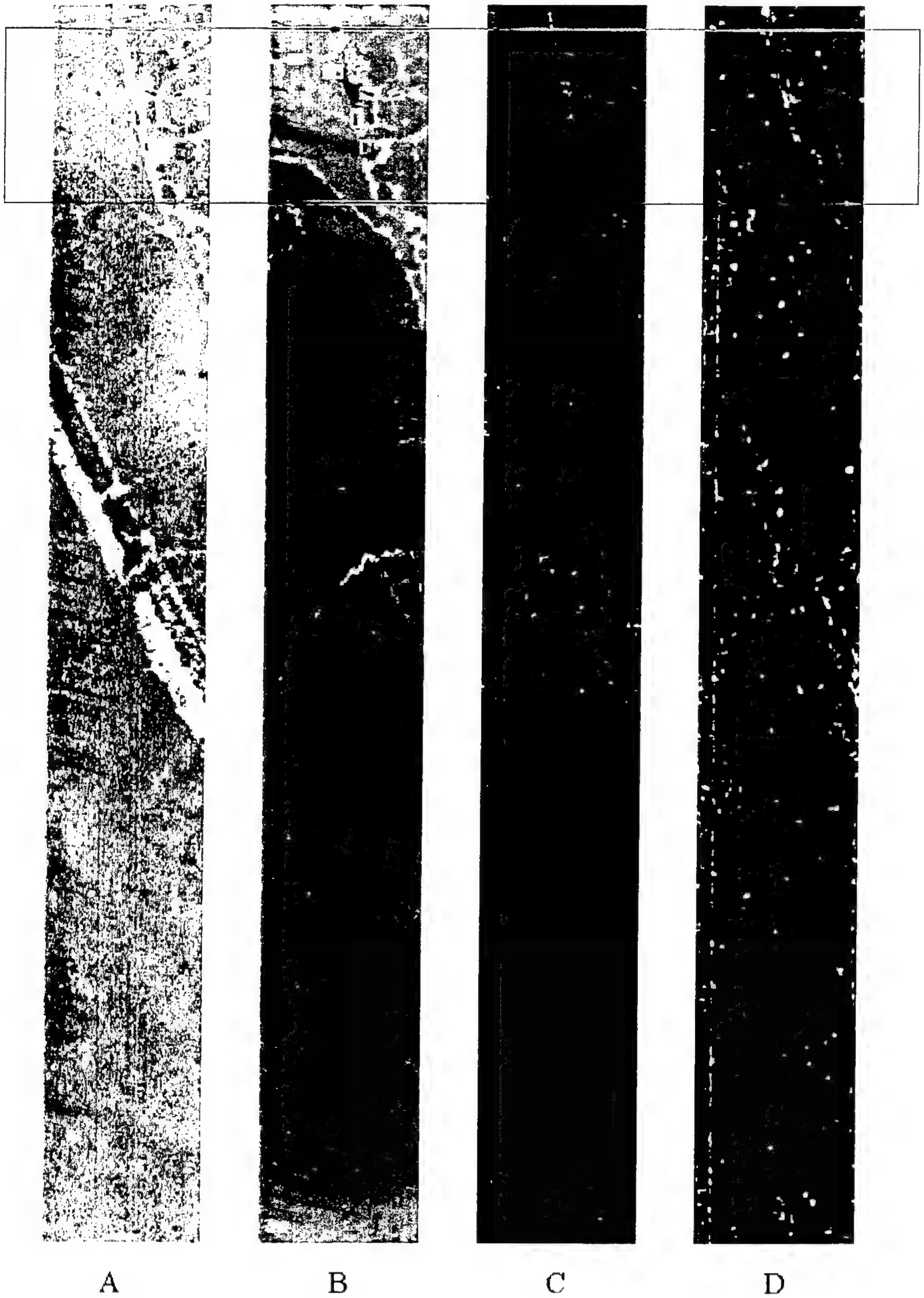

Figure 16: Mission 3 Site 6 Detection Results. (A) Broadband Image, (B) Color PC Image with Target Truth Mask, (C) Optimized RX Detection Output and (D) Optimized LBG Detection Output.

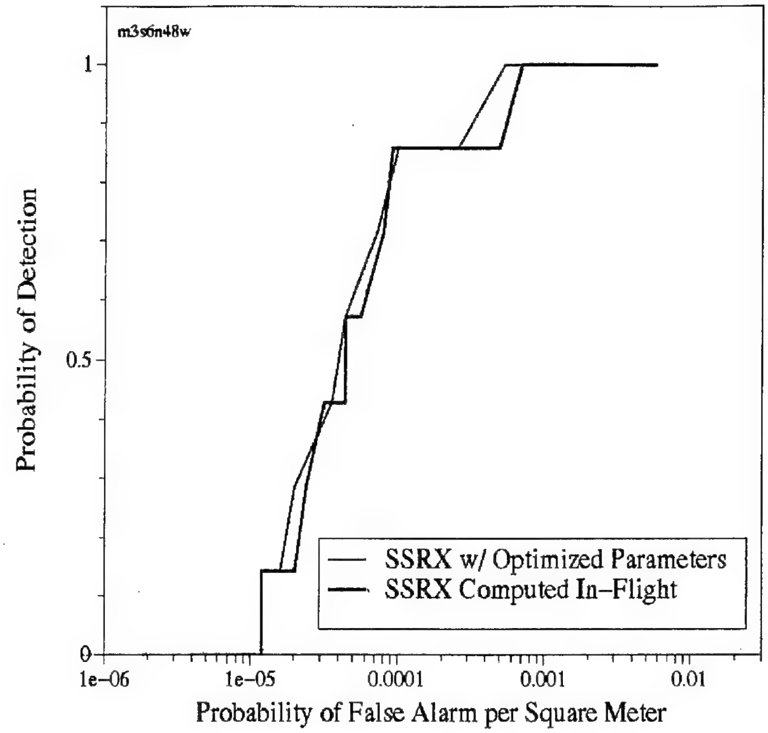

Figure 17: Mission 3 Site 6 RX Detection Results.

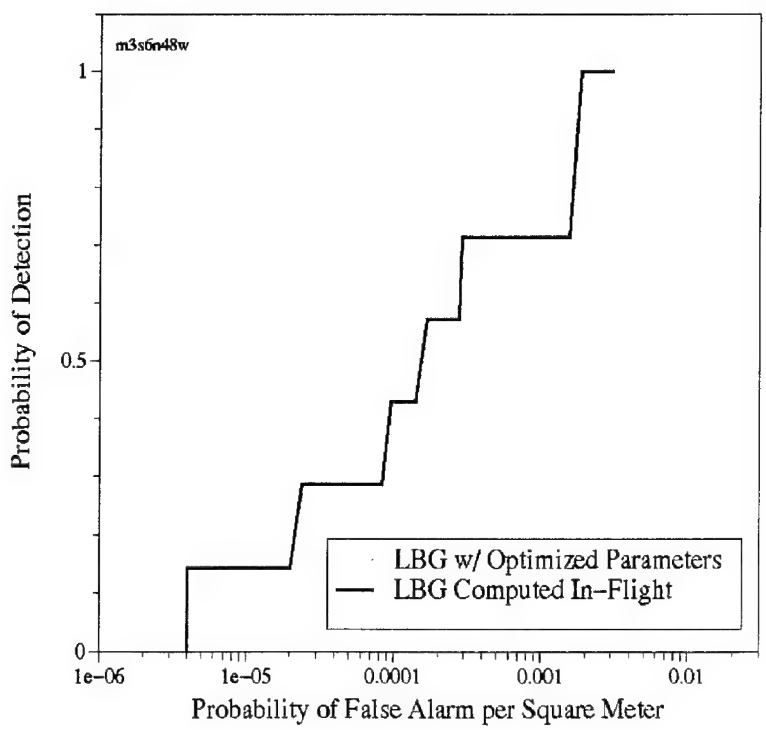

Figure 18: Mission 3 Site 6 LBG Detection Results.

6. SUMMARY

The preceding has provided an overview of the DH2 hyperspectral sensor system and the recent field experiment in which it was employed. Successful integration of the NRL DH2 real-time processor and the SEBASS LWIR sensor has been achieved. Field tests demonstrated real-time airborne LWIR detection of targets with good ROC performance using two simultaneous anomaly detection algorithms (s-RX and LBG). And finally, numerous fully corrected and calibrated LWIR data cubes were obtained in real-time. These high-quality data sets (LW&MW) will be used for future development of other tactically robust algorithms.

7. ACKNOWLEDGEMENTS

The authors would like to thank Alan Stocker, William Schaff, Clark Olifant and Eskander Ensafi of Space Computer Corporation for their contributions to the real-time processor system and for their assistance during the field data collect. A special thanks goes to Alan Stocker for providing some of the preliminary algorithm performance results. The authors would also like to thank John Hackwell, Niel Schulenburg, Brad Johnson, Steve Hansel, Cameron Purcell, Eric Keim, Rich Boucher and Tom Hayhurst for their contributions to the SEBASS sensor system integration and for their support during the field data collect. A special thanks goes to Neil Schulenburg for providing technical information on the SEBASS sensor.

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9. APPENDIX

Dark HORSE 2 / HYDRA

Flight Log and Quick-Look Summary

1. Summary listing: Best of DH2 / HYDRA

Site 3	m3s3n69n_19981107_030711[2943]
Site 4	All: targets_19981101_170745/north/pcbands m4s4n143n_19981108_023551 m4s4n60e_19981108_012603 Rem: m3s4n83n_19981107_031856 m3s6n48w_19981107_024946 m3s4n27e_19981107_023523
Site 5	m2s5n54n_19981105_132113 / pc bands 5-7 / Good on ENVI. Site 5 = L300! m3s5n55n_19981107_025516 m4s5n108n_19981108_020557
Site 6	m2s6n109n_19981105_140550/pc bands 5 / Site 6 at L1370 m2s6n47n_19981105_131532 / Looks good on ENVI. Site 6 = L300 m3s6n13w_19981107_013924 m4s6n67w_19981108_013144
Site 7	m3s7n6n_19981107_021802 m4s7n122n_19981108_021753 m2s7n61n_19981105_132641
Site 9	m1s9_19981104_090429
Site 12	m2s12n68n_19981105_133240
S9 Freon	m4s9n46n_19981108_010710 / (4 lb) / Release at L3389. m4s9n53n_19981108_011835 / (26 lb)

Note: To transform from ENVI image to north up (for northbound flights):
Step1: Rotate 90 deg with transpose
Step 2: Rotate 180 deg.

2. Summary of Change Detection Experiment

Mission	Change Detection Configuration
MS / Sun	All tanks at s4
M1 / Wed	All tanks at s4
M2 / Thur	Targets P1, P4, & P5 removed. Put in parking lot.
M3 / Fri	Targets P1, P4, & P5 still absent.
M4 / Sat	All tanks at s4.
M5 / Mon	All tanks at s4.
M6 / Tue	Targets P1, P4, & P5 removed. Two placed on showline (s2). One used to generate smoke. Cancelled due to weather.

3. Column Heading Nomenclature:

Name	Meaning
"Mission 3"	Mission 3 as defined by HYDRA Data Collection Plan
Session	Aerospace/SEBASS terminology for a collection of shots, equal to the Zulu time at the start of a data collection. There may be more than one session per flight.
File	File name as generated automatically
Site	Target site for a particular run
Shot	SEBASS shot number as tabulated on SEBASS Flight Log
SOG Gnd Speed	Speed Over Ground (meters/sec)
COG Direction	Course Over Ground (true heading (GPS))
Altitude	Column header for altitude (meters)
Comments	Comments for given run(shot) Black = comments from SEBASS flight log & Esky notes Red = comments generated by viewing file on realtime processor Blue = comments generated by viewing xv file using ENVI.

4. Filename Nomenclature

m2s6n47n_19981105_131532	**Mission 2**
m2**s6**n47n_19981105_131532	**Site 6**
m2s6**n47**n_19981105_131532	**Shot number 47**
m2s6n47**n**_19981105_131532	**north-bound**
m2s6n47n_**1998**1105_131532	**Year**
m2s6n47n_1998**1105**_131532	**Date (Zulu)**
m2s6n47n_19981105_**131532**	**Time (Zulu) at start of data***

Example: "m2s6n47n_19981105_131532"
*Note: *Local time(Eglin AFB, FL) = GMT - 6hrs*

Dark HORSE 2 / HYDRA

Flight Log and Quick-Look Summary

Mission S
Sunday 1 Nov 98 / ~1530-1715

File		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
							All tanks s4					
target_19981101_170545		4	na	na	na	na		128		30	1024	FP
targets_19981101_170745		4	na	na	na	na	Great pass over site 4. Site 3 not yet up.	128	1837	30	1024	FP

Mission 1
Wednesday 4 Nov 98 / 0830-1030

File (PST-1hr)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
							All tanks site 4	Session 981104_143238				
m1s4_19981104_074730	x	4	na	na	na	na	Eske original Missed to west. Part of site 3.	128	303	30	1024	FP
m1s4_19981104_075226	x	4	6	124	129	862	missed	128	478	30	1024	FP
m1s4_19981104_075334		4	13	131	176	867	Got all of S3 also Missed slightly to west. Got some site 4	128	284	30	1024	FP
m1s6_19981104_080026		6	20	108	84	864	Think got all	128		30	1024	FP
m1s5_19981104_080830	x	5	27	127	179	856	Not sure got targ. May have done wrong.	128		30	1024	FP
m1s7_19981104_081515		7	34	121	177	859	got it	128		30	1024	FP
m1s3_19981104_082120		3	41	117	180	853	got it. also site4!	128		30	1024	FP
m1s4_19981104_082719		4	48	108	94	837	got it Good RT results.	128	416	30	1024	FP
m1s6_19981104_083423		6	55	111	81	869	good one?	128		30	1024	FP
m1s5_19981104_084220		5	62	125	88	854		128	505	30	1024	FP
m1s5_19981104_084717		5	69	125	183	850	got it. Some bad data. Pilot radio interference?	128	511	30	1024	FP
m1s7_19981104_085352		7	76	116	178	871	got most except targs to left	128		30	1024	FP
m1s7_19981104_085853		7	83	121	174	846	got it	128		30	1024	FP
m1s9_19981104_090429		9	90	106	357	856	got it	128		30	1024	FP
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Dark HORSE 2 / HYDRA

Flight Log and Quick-Look Summary

Mission 2
Thursday 5 Nov 98 / 0600-0800

Clear & cold(40's). Some fog and low clouds over site	Tanks removed	Session 981105_121853

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Band s*	*Head*	*Type*
m2s4n6n_19981105_122859	x	4	6	107	1.9	824	looks good Way to left(west). Only a few site 4!! All of site 3	128	1160	30	1024	FP
aborted	x		13				no good / aborted	128		30	1024	FP
m2s4n20n_19981105_124303	x	4	20	102	3.4	818	looks good Too far left. Lots of site3. Not all of 4	128	629	30	1024	FP
m2s6n33w_19981105_130430	x	6	33	100	284	804	maybe not all targets Probably got all of 6	128	1993	30	1024	FP
m2s6n40n_19981105_131105	x	6	40	97	357	808	probably missed Probably missed	128		30	1024	FP
m2s6n47n_19981105_131532		6	47	110	350	816	looks good! Maybe site 5 also. No. Looks good on ENVI. Site 6 = L300	128	1154	30	1024	FP
m2s5n54n_19981105_132113		5	54	98	345	810	Good on ENVI. Site 5 = L300! pc bands 5-7	128	1118	30	1024	FP
m2s7n61n_19981105_132641		7	61	99	357	846	looked good Slightly to left(west). Got targets	128		30	1024	FP
m2s12n68n_19981105_133240		12	68	97	354	842	hit it. some low clouds site 12 = resolution chart	128	1127	30	1024	FP
bad cal. no data		x	75	94	356	843	site9. also got site 7 in shot	128		30	1024	FP
m2s3n88n_19981105_134739		3	88	107	2	841	got it. probably some of site 4 also Off to left(west). Got a tank in trees?	128	2995	30	1024	FP
m2s4n95n_19981105_135336		4	95	107	2.4	840	nailed it plus site 3 OK And all of site 3--	128	4017	30	1024	FP
m2s6n102n_19981105_140008	x	6	102	107	357	840	under clouds Looked OK Some of site5?	128	970	30	1024	FP
m2s6n109n_19981105_140550		6	109	107	3	839	nailed it. also got site 5 Some clouds over north portion of site 5 at L1530. Not as good as 1105_132113 for site 5. Site 6 at L1370	128	2453	30	1024	FP
m2s7n116n_19981105_141049		7	116	105	359	840	got it. lots of clouds before+after targets Got it.	128		30	1024	FP
m2s4n123n_19981105_141623	x	4	123	106	348	839	got it Too far left. Got some of 4.	128	3281	30	1024	FP
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Dark HORSE 2 / HYDRA

Flight Log and Quick-Look Summary

Mission 3
Friday 6 Nov 98 / 1900-2130

Clear & cold(40's). / after sunset / calm	Tanks removed	Session 981107_011825

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
							needed to restart session due to operator error					
m3s4n6n_19981107_013003		4	6	109	0.8	832	Good hit on site 4n. some of site 3.	128		30	1024	FP
m3s6n13w_19981107_013924		6	13	112	268	836	Good hit on site 6w. Got north third of site 4.	128	2943	30	1024	FP
m3s5n20n_19981107_014514		5	20	107	355	827	Good hit on site 6n. Missed site 5.	128		30	1024	FP
m3s5n27n_19981107_015109		5	27	105	2.2	864	Good hit on site 5n. Some of site 6.	128		30	1024	FP
m3s7n34n_19981107_015730		7	34	110	357	840	Missed to east.??	128		30	1024	FP
m3s7n41n_19981107_020231	x	7	41	108	354	861	Slightly off to west.	128		30	1024	FP
							SPARC froze, had to start new session	x	x	x	x	x

Clear & cold(40's).		Session 981107_020736

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
m3s7n6n_19981107_021802		7	6	110	358	859	Got all of site 7n.	128		30	1024	FP
m3s3n13n_19981107_022434		3	13	108	0.0	110	All of site 3n. Slightly off to west.	128	1834	30	1024	FP
m3s4n20e_19981107_023036	x	4	20	111	76	865	Missed slightly to south.	128		30	1024	FP
m3s4n27e_19981107_023523		4	27	113	93	855	Got all of site 4e.	128		30	1024	FP
m3s4n34n_19981107_024005		4	34	114	4	846	Great hit on site 4n. Some of site 3.	128		30	1024	FP
na/bad cal	x	6	41	119	272	862	bad cal	x	x	x	x	x
m3s6n48w_19981107_024946		6	48	115	268	854	Got all of site 4w & site 6w.	128	3381	30	1024	FP
m3s5n55n_19981107_025516		5	55	107	359	873	Got all of site 5n. Some of site 6.	128		30	1024	FP
m3s9n62n_19981107_030049	x	9	62	107	0.9	854	Missed site 9 ??(no lights). Swamp = bright?	128		30	1024	FP
m3s3n69n_19981107_030711		3	69	116	3.0	875	Got all of site 3n. Some of s4.	128	2647	30	1024	FP
m3s4n76n_19981107_031337	x	4	76	113	0.7	865	Slightly to east on site 4.	128		30	1024	FP
m3s4n83n_19981107_031856		4	83	111	357	844	Perfect hit on site 4n. All of site 3 also.	128		30	1024	FP

Mission 4
Saturday 7 Nov 98 / 1800-2030

Clear / 20 kt winds at altitude / all after sunset | All tanks at s4. | Session 981108_001044

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
m4s9n25n_19981108_003956	x	9	25	110	356	870	Missed. 4.4 lb Freon release. Probably got site 7. Calib seems to be drifting. Tom H. says probably bad cal here	128		30	1024	FP
m4s9n32n_19981108_005033		9	32	108	354	871	Got it. Freon gas flowing; 4.2 lb release. Should have all "X" targets. Got ATARS. See large plume.	128	2694	30	1024	FP
m4s4n39n_19981108_005710		4	39	110	270	868	Got it. Other Twin Otter in view. All of site 4.	128		30	1024	FP
m4s9n46n_19981108_010710		9	46	112	0.0	867	Got it. 4.4. lb release. All "X" in filed. Got ATARS. Release at L3389.	128	3389	30	1024	FP
m4s9n53n_19981108_011835		9	53	116	359	883	Got it. 26.8 lb Freon release.	128		30	1024	FP
m4s4n60e_19981108_012603		4	60	107	87	871	Got it. Image became brighter for approx 100 frames at 01:24 GMT as if prolonged version of the horizontal striping effect. Only E-W flight over site 4. One targ at extreme edge.	128		30	1024	FP
m4s6n67w_19981108_013144		6	67	112	268	870	Got it. Good site 6.	128		30	1024	FP
m4s5n74n_19981108_013701	x	5	74	114	0.0	866	Missed. Lights not visible Also bad pixels.	128		30	1024	FP
m4s5n81n_19981108_014441	x	5	81	114	356	866	Got site 7. Missed site 5.	128		30	1024	FP
m4s5n88n_19981108_015135	x	5	88	117	355	853	Got part of site 5. Got site 6.	128		30	1024	FP
m4s5n95n_19981108_015823	x	5	95	118	356	858	Missed. No lights. Missed to east.	128		30	1024	FP
m4s5n108n_19981108_020557		5	108	114	0	862	Got it. Finally! Good site 5.	128		30	1024	FP
m4s7n115n_19981108_020557	x	7	115	117	352	852	Missed. Missed to west.	128		30	1024	FP
m4s7n122n_19981108_021753		7	122	120	350	875	Got it.	128		30	1024	FP
m4s3n129n_19981108_022359		3	129	122	359	844	Got it. Got silica, too. All of site 3, 2/3 of site 4.	128		30	1024	FP
m4s4n136n_19981108_023007	x	4	136	117	359	860	Just missed. Got site 3 Missed some of site 4.	128		30	1024	FP
m4s4n143n_19981108_023551		4	143	118	356	851	Got it & site 3. Got all of site 4, some of site 3, and the silica.	128	2438	30	1024	FP

Mission 5
Monday 9 Nov 98 / 1800-2030

Foggy, clouds at ~3000 ft	All tanks at site 4	Session 981109_110650

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
m5s4n6n_19981109_112253	x	4	6	115	359	874	Missed some. Too far east	128		30	1024	FP
m5s4n13n_19981109_112905		4	13	113	358	872	All of site 3, too. Good shot of site 4.	128	943	30	1024	FP
m5s6n20w_19981109_113633	x	6	20	111	271	887	Site 4, too. Missed, started too late.	128		30	1024	FP
m5s5n27n_19981109_114108	x	5	27	120	351	863	Good shot of site 5.	128		30	1024	FP
m5s7n34n_19981109_114721		7	34	119	358	878	Good shot of site 7.	128		30	1024	FP
m5s3n41n_19981109_115325		3	41	145	355	872	All of s3 but somewhat to west.	128		30	1024	FP
m5s4n48n_19981109_115856		4	48	117	356	866	All of site 4, slightly to east.	128		30	1024	FP
m5s6n55w_19981109_120528		6	55	114	264	894	Site 4, too. Good shot of site 6w. South 2/3 of site 4.	128		30	1024	FP
m5s5n62n_19981109_121038	x	5	62	121	354	877	Missed.	128		30	1024	FP
m5s5n69n_19981109_121622	x	5	69	120	356	857	Started too late.	128		30	1024	FP
m5s9n76n_19981109_122250		9	76	117	0	885	1 to 3 kt N to S ??? ????? Good shot of acetone release. Some of ATARS targ	128		30	1024	FP
m5s9n83n_19981109_123012		9	83	121	358	867	Lines on ATARS thermally resolved. Good shot of acetone release. Most of ATARS	128		30	1024	FP
m5s9n90n_19981109_123801		9	90	114	1	879	306 ml flow on all 3 ???? Good shot of acetone release. Some of ATARS	128		30	1024	FP
m5s9n97n_19981109_130132		9	97	114	358	876	Good shot of acetone release. All of ATARS	128		30	1024	FP

	All tanks at site 4	Session 981109_124602

File (Zulu time)		Site	Shot	SOG Gnd Speed	COG Dir	Alt(m)	Comments	*Pix*	*Lines*	*Bands*	*Head*	*Type*
m5s4-6n18w_19981109_130132		6x	18	120	267	1898	Site 5,6,3 maybe 4. All of s3, north 2/3 of s4.	128		30	1024	FP
		6x	25	129	359	1890	Site 3 &4.	128		30	1024	FP
m5s5-6n32n_19981109_131310		6x	32	127	356	1890	Sites 5,6. Good shots of both 5&6.	128		30	1024	FP
m5s7-9n39n_19981109_132002		6x	39	125	356	1875	Site 7, site 9. Good shot of s7 and s9.	128		30	1024	FP